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THE LINKS BETWEEN LAND USE AND WATER QUALITY FOR FRESHWATER PEARL MUSSEL, MARGARITIFERA MARGARITIFERA, IN THE RIVER SOUTH ESK, SCOTLAND

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ABSTRACT: The freshwater pearl mussel, *Margaritifera margaritifera*, is an endangered species and its population has decreased rapidly over the last century. Scotland is the home to half of the known populations of *M. margaritifera*. Land use is a significant factor affecting water quality as well as the distribution of freshwater pearl mussels. Thirty eight sites in River South Esk were selected to investigate the impacts of land use on water conductivity, pH and the concentration of nitrate and phosphorus on the distribution of mussels. *M. margaritifera* was more abundant in habitats in woodland with low and stable water nutrient level. Water chemical analysis indicates that pollutant concentration is related to the vegetation of river catchments. River water passing woodland has a relatively better quality and overhanging boughs of trees create shadows which attract mussels. Livestock pasture catchments seem to have less significant chemical effects, but animal activities may disturb the habitat of mussels and increase water turbidity. Water pollution in irrigated crop land is relatively higher. Heather moorland is of less concern because of its inappropriate channel type for mussels. Waters in the vicinity of housing, roads and bridges seem to be avoided by mussels. *Margaritifera margaritifera* did not show any preference on the type of shadows. Living mussels have been discovered at the sites which have shadows created by overhanging branches or high riverbanks.

Keywords: Margaritifera margaritifera, Land use, Water quality, Unionoida, woodland

1. INTRODUCTION

Land use surrounding waterways has a significant influence on the abiotic and biotic conditions present [1]. Land clearing can affect the water quality of rivers [2], [3]. Consequently, the biota within waterways can also be impacted [4]-[6]. Nowadays, human activity plays a major role in disturbing river catchments all over the world. Thus, a large number of aquatic species are under threat due to human influences.

Freshwater mussels (Mollusca: Bivalvia: Unionoida) are important for both local ecosystems and humans. Firstly, mussels act as “ecological generalists” and are able to benefit the biodiversity and productivity of freshwater communities [7], [8]. The filter feeding function of freshwater mussels directly improves water clarity and quality [7], [9], [10]. Furthermore, freshwater mussels help to enhance the nutrient transportation connecting the benthic and pelagic layers of water bodies [11]-[13]. Moreover, shells of mussels also become shelters of many benthic species [14], [15]. Economically, freshwater pearl mussels have been harvested as a source of pearls and mother-of pearls from pre-history [16]-[18]. Mussel meat has been taken as a food source by people as well [16], [19]. Environmentalists have used freshwater mussels as bio-indictors for determining the health of water bodies [20], [21].

Unfortunately, despite their importance, freshwater mussels are also endangered throughout the world. The freshwater pearl mussel, *Margaritifera margaritifera* was abundant and widely distributed in Europe for thousands of years [22], [23]. However, populations of *M. margaritifera* have decreased dramatically in recent years [24], [25]. An earlier estimation has claimed that *M. margaritifera* will be extinct by 2025 as a result of overfishing and habitat degeneration [23], [26], [27]. Recent research has confirmed the potential impact of land use on the recruitment of juvenile *M. margaritifera* [28].

Scotland is the home to over half of the known populations of *Margaritifera margaritifera* and a key spot for the conservation of this species [25]. Unsurprisingly, freshwater pearl mussels in Scotland are also suffering those events causing the decline of their population [27]. Thus, the potential link between catchment land use and the abundance of *M. margaritifera* needs to be considered for better river habitat management.

This investigation firstly attempted to discover the relationship between riparian land use and the presence of mussels in River South Esk, Scotland. Additionally, selected parameters for water chemistry were analyzed, since catchment land use is also able to affect water quality.

2. MATERIALS AND METHODS

Thirty eight sites were selected for visual survey. Land use information was obtained from DigiMap® and confirmed in fieldwork. A buffer zone up to 50m width and the vegetation within 5m from the riparian zone was investigated in the survey. Main land uses of the River South Esk catchment were categorized as four types: heather moorland, livestock pasture, woodland and irrigated crop land [29]-[31]. Channel and bank features were assessed during fieldwork in spring-summer by using the method employed by the Scottish Environment Protection Agency (SEPA) [32]. The vegetation types within the 5m width buffer zone were categorized as either trees or grass.

Fig. 1 Catchment and location of the River South Esk in Scotland [29]

Abundance of mussels was classified based on the visible number of mussels [33]. Searching started from the access point of the river and continued for up to 50m upstream unless the channel condition was inadequate. Mussels were counted by visual inspection to avoid disturbance. No mussels were harmed or taken out of the river in the fieldwork.

General water quality information was obtained from [32]. Conductivity, Dissolved Oxygen (DO) and pH were measured at the site. Nitrate and phosphate levels were examined within 24 hours after sampling. Water samples were collected on one occasion.

All data analyses were conducted with R software. The differences in mussel population, as well as water chemical parameters, in the four types of land use categories, was analyzed by one-way ANOVA. The linear relationships of the mussel population, water chemistry and landscape categories were analyzed by general linear regression.

3. RESULTS

The abundance of mussels was significantly influenced by land use in the catchment, with more mussels found in woodland than in pasture or crop land and no mussels found in heath moorland (ANOVA: df=3, F=8.63, P<0.001, Fig. 2). The linear regression model suggested that woodland in the 50m width buffer zone could be the most significant predictor for the distribution of mussels and a positive relationship might exist (general linear regression: estimate coefficient=1.234 t-test t=1.959 P=0.06). Pasture, irrigated crop land and heather moorland seemed to be in a negative relation to the abundance of mussels but did not show a statistical significance (general linear regression: all t-test |t|<1 P>0.4). Statistical results also did not illustrate a clear relationship between vegetation type within the 5 m buffer zone and the population of freshwater pearl mussels (ANOVA analysis: P=0.15, general linear regression P=0.19). Additionally, habitat assessment recorded that shade from either overhanging boughs or river bank higher than 5m was present in the sites where living mussels were discovered.

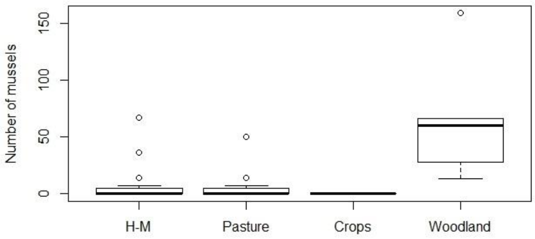

Fig. 2 Population of *Margaritifera margaritifera* with 50m buffer zone land use: Heather moorland (H-M), livestock pasture (Pasture), irrigated crop land (Crops) & Woodland (Woodland).

Water chemistry analysis also demonstrated that the pollution in woodlands is relatively lower than other types of land use (Fig. 3). Water nitrate, dissolved oxygen and conductivity proved to be negatively affected by woodland (estimate coefficient: N=-1.27, DO=-0.17, Conductivity=-0.57; t-test t: N=-2.13, DO=-2.49, Conductivity=-2.57; t-test P: N=0.04, DO=0.02, Conductivity=0.015). Difference of DO and conductivity in four strata of land use was also statistically significant (ANVOA DO: df=3, F=3.37, P=0.03; Conductivity: df=3, F=5.65, P=0.003). Furthermore, trees in the 5m buffer zone was discovered to have positive impacts on dissolved oxygen (estimate coefficient=0.18, t-test t=2.64, t-test P=0.01, Fig. 4). Moreover, conductivity level in the 5m buffer zone with trees was higher than the buffer zone with grass (ANOVA: df=1, F=6, P=0.0187, Fig. 5). Last, the rest of the statistical results concerning the relationship between landscape and water quality were out of the confidence interval.

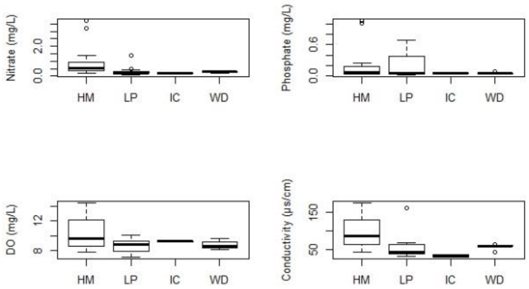

Fig. 3 Pollutant concentration in heather moorland (HM), livestock pasture (LP), irrigated crop land (IC) and woodland (WD).

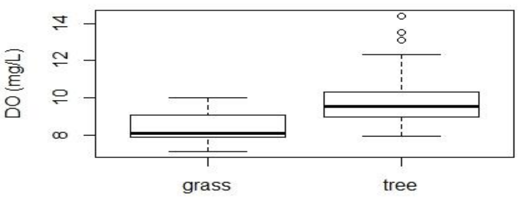

Fig. 4 Dissolved Oxygen of river water coinciding with the landscape of 5m width buffer zone.

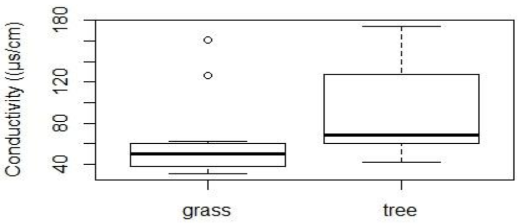

Fig. 5 Water conductivity coinciding with the vegetation type of 5m buffer zone.

General linear regression only illustrated a clear negative relationship between mussel abundance and water dissolved oxygen (estimate coefficient=-0.63 t-test t=-2.258 P=0.03, Fig. 6). Other water quality indicators demonstrated a range in the habitat of freshwater pearl mussels but did not have any confident linear relation (Fig. 7). The variation range of selected water chemical indicators was recorded in Table 1.

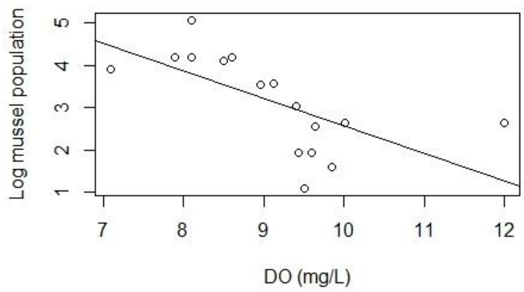

Fig. 6 Linear regression of the abundance of *Margaritifera margaritifera* and DO level of river water.

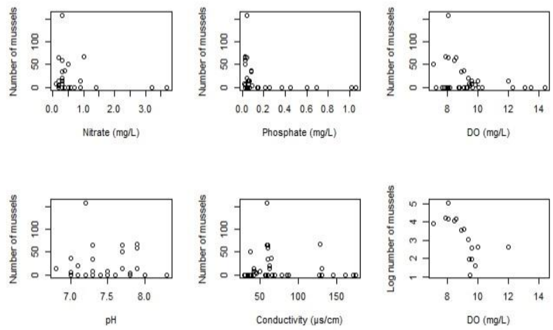

Fig. 7 Abundance of *Margaritifera margaritifera* and water quality.

Table 1: Water quality ranges in the surveyed mussel habitat

Chemical Indicator	Range
$N(NO_3^-)$ (mg/L)	0.1~1.0
$P(PO_4^-)$ (mg/L)	0.02~0.09
DO (mg/L)	7.1~12
pH	6.8~7.9
Conductivity (μ s/cm)	37.30~130.70

4. DISCUSSION

Woodland may be able to positively affect the population density of *Margaritifera margaritifera*. The concentrations of nitrates and phosphates were lower in the forested areas of the river which is the same as the conclusion in [34]. In this research, the largest population of freshwater pearl mussels were discovered in the channel within woodland. Besides, water salinity, a crucial factor affecting freshwater mussels, was less variable when flowing through woodland. Furthermore, the DO level in woodland was relatively stable although not extremely high. Other studies also have shown that organic and inorganic carbon nutrients were relatively lower in forested streams, possibly because of a reduction in water turbidity [34], [35].

Other positive effects of woodland are associated with the shadows created by overhanging boughs and exposed roots [36]. Algal blooms may be toxic to freshwater pearl mussels, and shady areas from trees, as well as lower dissolved oxygen in this region, can limit their occurrence [27], [36]. In this and previous studies, no mussels were found in sections of the river that flowed through heather moorland and density of mussels was reduced in river reaches in livestock pasture and crop land [30], [31]. Furthermore, all discovered mussels were in the shade of trees or high bank in this project as in [30]. Thus, clearing of woodland can be detrimental for the conservation of freshwater pearl mussels [37], [38].

In addition to the importance of water quality and shading on mussel density, roads, bridges and houses may have several negative impacts on mussels [39]. Mussels were also observed to avoid these types of catchments in this survey. For instance, runoff, sedimentation and disturbing of human activities can become a problem although no such event was observed in this research. However, these were reasons in the past for large mortality in mussel populations and should therefore be re-considered as an ongoing threat [40].

The water quality requirements of *M. margaritifera* may also vary among populations as indicated in [30]. Although it is suspected that *M. margaritifera* is sensitive to water quality changes [26], [27], there are freshwater pearl mussels inhabiting reaches which are classified as having poor water quality by SEPA [41]. The water quality results of this survey also did not strictly follow the conclusions proposed in previous studies (Table 2) [26], [42]. While the average nitrate concentration of water stayed within suggested levels, the average level of phosphate exceeded the recommended range. Moreover, DO level had a negative relationship with the number of mussels. Mussels are able to adapt to environmental changes, especially when change is gradual [39], so this variation is not unexpected.

Table 2: Nitrate and phosphate concentration in mussel habitat and target

	$N(NO_3^-)$(mg/L)	$P(PO_4^-)$(mg/L)
Mean	0.3562	0.0487
Range	0.1~1.0	0.02~0.09
Target[26]	< 0.5	<0.03
Target[42]	<1.0	<0.03

5. CONCLUSION

This research has demonstrated that woodland has potential positive effects on *Margaritifera margaritifera*. Therefore, the protection of riparian woodland is important for the conservation and management of freshwater pearl mussels. Land clearance in such areas needs to be reconsidered with care. The combination of large scale land use information and small scale microhabitat investigation is helpful for research concerning species conservation [43].

Questions remain for further studies. This research selected 50m as the buffer zone, which may not be applicable for other research purposes. Furthermore, the conservation of freshwater pearl mussel requires the protection of both the mussels and the host fishes, trout and salmon. Moreover, the model for protecting freshwater systems is complex [40], so a proposal for universal protection may be better than focusing on several selected species.

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